

23 Gauge Mediation: Part I

23.1 Modules

The basic idea of gauge mediation is that there are three sectors in the theory, a dynamical SUSY breaking sector, a messenger sector, and the MSSM. SUSY breaking is communicated to the messenger sector so that the messengers have a SUSY breaking spectrum. They also have SM gauge interactions, which then communicate SUSY breaking to the ordinary superpartners. We will take a model with N_f messengers $\phi_i, \bar{\phi}_i$ and a Goldstino multiplet X

$$\langle X \rangle = M + \theta^2 F \quad (23.1)$$

with a superpotential

$$W = X \bar{\phi}_i \phi_i . \quad (23.2)$$

In order to preserve gauge unification, ϕ_i and $\bar{\phi}_i$ should form complete GUT multiplets. This shifts the coupling at the GUT scale by

$$\delta\alpha_{\text{GUT}}^{-1} = -\frac{N}{2\pi} \ln\left(\frac{\mu_{\text{GUT}}}{M}\right) , \quad (23.3)$$

where

$$N = \sum_{i=1}^{N_f} 2T(r_i) . \quad (23.4)$$

For the unification to remain perturbative we need

$$N < \frac{150}{\ln\left(\frac{\mu_{\text{GUT}}}{M}\right)} \quad (23.5)$$

The VEV of X gives each messenger fermions a mass M , and the scalars squared masses $M^2 \pm F$. We will be interested in the case that $F \ll M^2$. We can construct an effective theory by integrating out the messengers.

23.2 RG Calculation of Masses

The pure gauge part of the Lagrangian is given by:

$$\mathcal{L}_G = -\frac{i}{16\pi} \int d^2\theta \tau(X, \mu) W^\alpha W_\alpha \quad (23.6)$$

Taylor expanding in the F component of X we find a gaugino mass

$$\begin{aligned} M_\lambda &= \frac{i}{2\tau} \frac{\partial \tau}{\partial X} \Big|_{X=M} F \\ &= \frac{i}{2} \frac{\partial \ln \tau}{\partial \ln X} \Big|_{X=M} \frac{F}{M} \end{aligned} \quad (23.7)$$

Since

$$\tau(X, \mu) = \tau(\mu_0) + i \frac{b'}{2\pi} \ln \left(\frac{X}{\mu_0} \right) + i \frac{b}{2\pi} \ln \left(\frac{\mu}{X} \right) \quad (23.8)$$

where

$$b' = b - N \quad (23.9)$$

So

$$M_\lambda = \frac{\alpha(\mu)}{4\pi} N \frac{F}{M} \quad (23.10)$$

Next consider the wavefunction renormalization for the matter fields of the MSSM

$$\mathcal{L} = \int d^4\theta Z(X, X^\dagger) Q^\dagger Q \quad (23.11)$$

where Z must be real. Taylor expanding we have

$$\mathcal{L} = \int d^4\theta \quad \left(Z + \frac{\partial Z}{\partial X} F\theta^2 + \frac{\partial Z}{\partial X^\dagger} F^\dagger \theta^{\dagger 2} + \frac{\partial^2 Z}{\partial X \partial X^\dagger} F\theta^2 F^\dagger \theta^{\dagger 2} \right) \Big|_{X=M} Q^\dagger Q \quad (23.12)$$

Canonically normalizing we have:

$$Q' = Z^{1/2} \left(1 + \frac{\partial Z}{\partial X} F\theta^2 \right) \Big|_{X=M} Q \quad (23.13)$$

$$\mathcal{L} = \int d^4\theta \quad \left[1 - \left(\frac{\partial \ln Z}{\partial X} \frac{\partial \ln Z}{\partial X^\dagger} - \frac{1}{Z} \frac{\partial^2 Z}{\partial X \partial X^\dagger} \right) F\theta^2 F^\dagger \theta^{\dagger 2} \right] \Big|_{X=M} Q'^\dagger Q' \quad (23.14)$$

So we have a sfermion mass term:

$$m_Q^2 = -\frac{\partial^2 \ln Z}{\partial \ln X \partial \ln X^\dagger} \Big|_{X=M} \frac{FF^\dagger}{MM^\dagger} \quad (23.15)$$

Rescaling the matter fields also introduces an A term in the effective potential from Taylor expanding the superpotential:

$$Z^{-1/2} \frac{\partial \ln Z}{\partial X} \Big|_{X=M} F Q' \frac{\partial W}{\partial Z^{-1/2} Q'} , \quad (23.16)$$

which is suppressed by a Yukawa coupling. To calculate Z , we do a SUSY calculation and replace M by $\sqrt{XX^\dagger}$. At l loops an RG analysis gives

$$\ln Z = \alpha(\mu_0)^{l-1} f(\alpha(\mu_0) L_0, \alpha(\mu_0) L_X) \quad (23.17)$$

where

$$L_0 = \ln \left(\frac{\mu^2}{\mu_0^2} \right) \quad (23.18)$$

$$L_X = \ln \left(\frac{\mu^2}{XX^\dagger} \right) \quad (23.19)$$

so

$$\frac{\partial^2 \ln Z}{\partial \ln X \partial \ln X^\dagger} = \alpha(\mu)^{l+1} h(\alpha(\mu) L_X) \quad (23.20)$$

So the two-loop scalar masses are determined by a one-loop RG eq.

At one-loop we have

$$\frac{d \ln Z}{d \ln \mu} = \frac{C_2(r)}{\pi} \alpha(\mu) \quad (23.21)$$

so

$$Z(\mu) = Z_0 \left(\frac{\alpha(\mu_0)}{\alpha(X)} \right)^{\frac{2C_2(r)}{b'}} \left(\frac{\alpha(X)}{\alpha(\mu)} \right)^{\frac{2C_2(r)}{b}} , \quad (23.22)$$

where

$$\alpha^{-1}(X) = \alpha^{-1}(\mu_0) + \frac{b'}{4\pi} \ln \left(\frac{XX^\dagger}{\mu_0^2} \right) \quad (23.23)$$

$$\alpha^{-1}(\mu) = \alpha^{-1}(X) + \frac{b}{4\pi} \ln \left(\frac{\mu^2}{XX^\dagger} \right) \quad (23.24)$$

So

$$m_Q^2 = 2C_2(r) \frac{\alpha(\mu)^2}{16\pi^2} N \left(\xi^2 + \frac{N}{b}(1 - \xi^2) \right) \left(\frac{F}{M} \right)^2, \quad (23.25)$$

where

$$\xi = \frac{1}{1 + \frac{b}{2\pi} \alpha(\mu) \ln \frac{M}{\mu}} \quad (23.26)$$

References

- [1] G.F. Giudice and R. Rattazzi hep-ph/9706540, hep-ph/9801271.